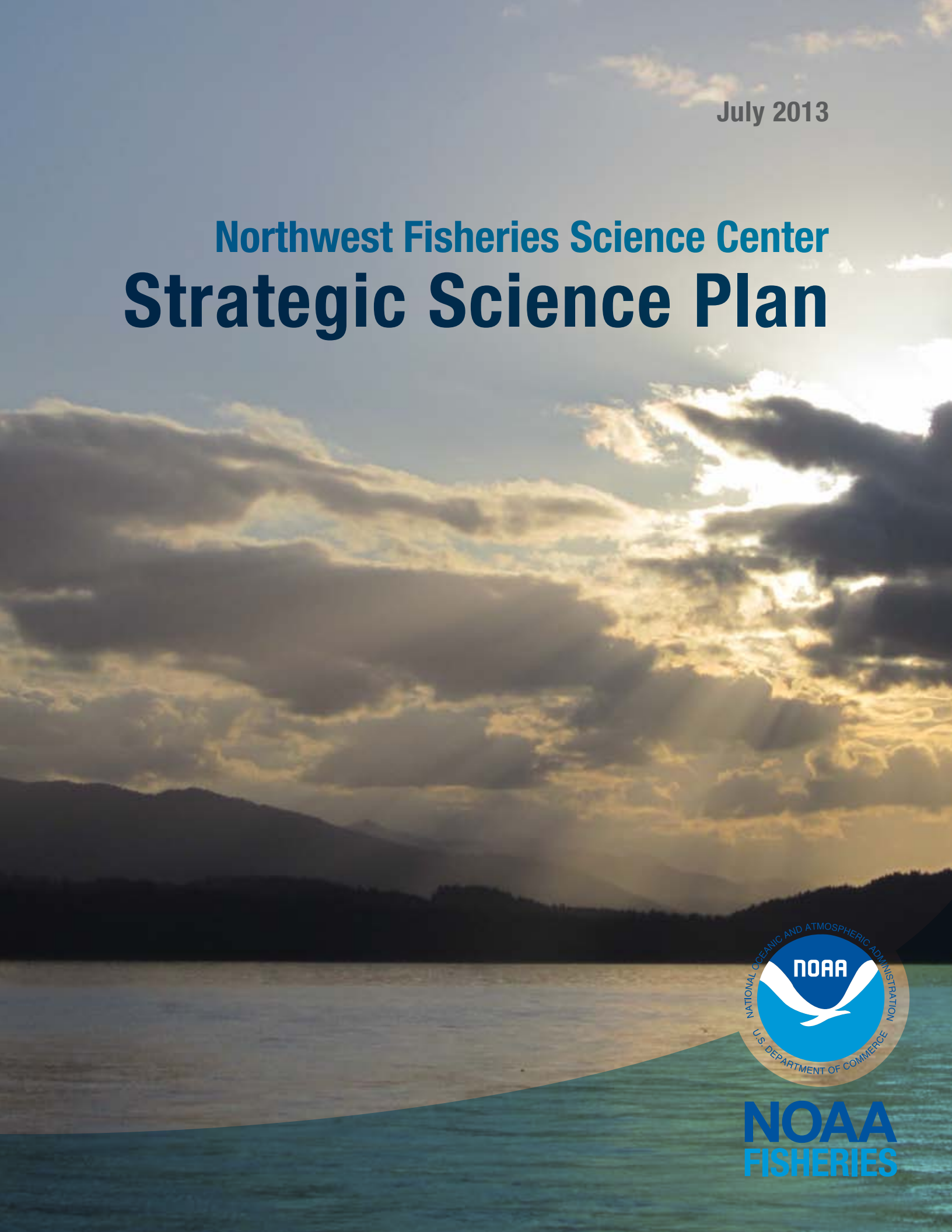

July 2013

Northwest Fisheries Science Center

Strategic Science Plan

NOAA FISHERIES

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U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

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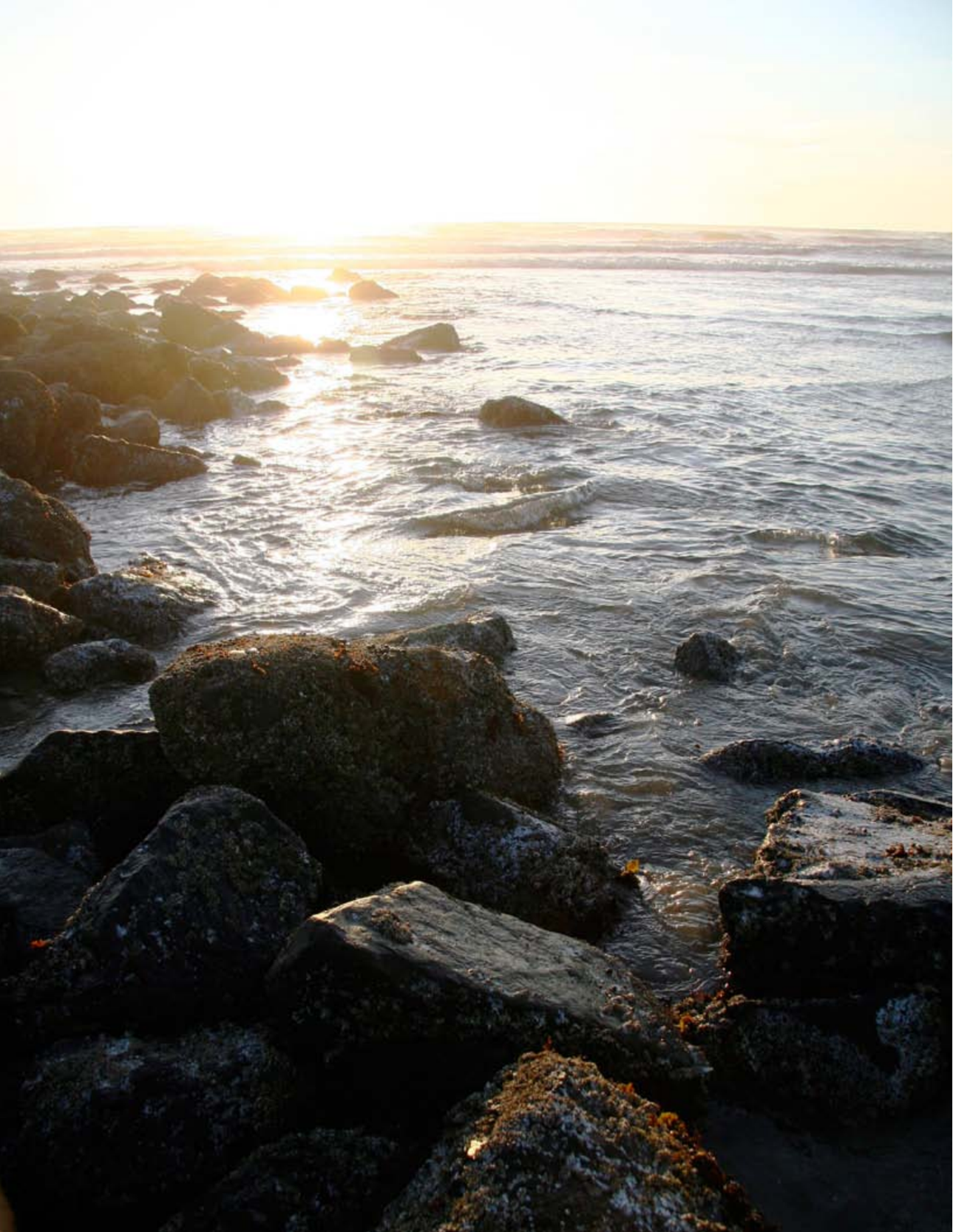

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NOAA Northwest Fisheries Science Center

Strategic Science Plan

Aerial view of the Northwest Fisheries Science Center, Seattle, Washington (SR-520 runs adjacent to the campus, at the bottom left hand corner)

Executive Summary

The Northwest Fisheries Science Center (NWFSC) conducts research to conserve and manage living marine resources and their marine, estuarine and freshwater habitat. The NWFSC's research supports the National Marine Fisheries Service's West Coast Regional Office and other agencies in managing more than 90 commercially important fish species, recovering over 30 threatened and endangered fish and marine mammal species, and identifying and mitigating coastal and ocean health risks. The NWFSC also fills an important role, together with the Southwest Fisheries Science Center, in providing the scientific knowledge to inform management decisions on the stewardship of the California Current Large Marine Ecosystem (CCLME). The California Current encompasses a broad range of coastal ecosystems, diverse habitats and biological communities. The CCLME provides vital habitat for living marine resources, economic development within coastal communities, and aesthetic enjoyment. NOAA Fisheries faces the immediate challenge of expanding research required to meet the Nation's needs and the geographical areas where the work is done, with limited resources. Recently, the NOAA Fisheries Science Board called for all Science Centers to revise existing or develop new strategic science plans in 2012 to be more responsive to agency and constituent needs. This NWFSC Strategic Science Plan addresses the research activities, infrastructure and support services envisioned over the next 3 to 5 years. At times, however, emerging regional or national priorities may arise that will require more immediate science-related input from the NWFSC. The NWFSC will respond to these emerging issues or new initiatives (i.e., Puget Sound Habitat Initiative, ocean planning) by developing a region-specific Annual Guidance Memo (AGM) that aligns closely with NOAA's AGM. This gives the NWFSC the flexibility to address emerging science and research directions not captured under the current Strategic Science Plan. The Strategic Science Plan will guide decision-making within the NWFSC by providing transparency, a framework for implementation, and direction for allocating Center resources to accomplish these goals.

The two dominant sections of this Strategic Research Plan are the (1) Research Themes and Foci and (2) Research Infrastructure and Support. Additional sections examine National Priorities for Ocean Research to provide context for the NWFSC's priorities, a description of NWFSC's role in providing science to support management, the skills and duties of support staff necessary to accomplish the science, and summary of the strategy for implementing this Strategic Plan.

Strategic Research Plan Outline:

- National Priorities for Ocean Research
- Role of the Northwest Fisheries Science Center
- NWFSC Research Themes and Foci
- Research Infrastructure and Support
  - Research Stations
  - Infrastructure: current capabilities and needs
    - Technologies
    - Models
    - Infrastructure
    - Science Communications
    - Strategies to meet future needs
- Support Staff
- Partnerships
- Implementation Strategy

Research Themes and Foci: The NWFSC's research effort is organized around four major themes (order does not reflect importance), and nineteen foci. The NWFSC incorporates climate research into each of these themes to improve understanding of the effects of climate on ecosystems. In addition, each theme also integrates social science research that seeks to better understand the human values, actions, communities and institutions that influence marine and anadromous fish, marine mammals, and other species and ecosystems in the Pacific Northwest.

Sustainable, Safe and Secure Seafood for Healthy Populations and Vibrant Communities

Effective fisheries management provides economic opportunities and ensures the long-term sustainability of fisheries and the habitats on which they depend. The NWFSC seeks to improve the quality and quantity of data used in stock assessments, the methods for assessing stocks and ecosystem sustainability within the context of human modification of the environment. The NWFSC also provides state-of-the-art science and technology to support aquaculture while protecting and maintaining ecosystem health. Further, pathogens, toxins from harmful algal blooms (HABs), chemical contaminants and other stressors of marine ecosystems pose significant risks to health of both seafood resources and to humans. The NWFSC focuses on research to improve understanding of those risks, how to forecast them, and identify means to mitigate their impacts.

Ecosystem Approach to Improve Management of Marine Resources

The California Current Large Marine Ecosystem, Puget Sound and the Columbia River Basin are home to a wide range of freshwater and marine resources that provide a wealth of ecosystem goods and services. Ensuring the resiliency and productivity of the California Current and Pacific Northwest ecosystems requires an integrated understanding of their structure, function, and vulnerability to increased human population growth in coastal communities and competing uses of coastal waterways and oceans. The NWFSC's approach to understanding these large ecosystems integrates studies across ecosystems (terrestrial, freshwater, and marine) and scientific disciplines to inform resource managers responsible for conserving marine resources.

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Recovery and Rebuilding of Marine and Coastal Species
The Pacific Northwest is home to several iconic endangered species, including Pacific salmon and killer whales, and several rockfish species. Mandates such as the Endangered Species Act, Magnuson-Stevens Act, and the Marine Mammal Protection Act, grant NOAA Fisheries the authority to manage the recovery of depleted species and stocks. The NWFSC contributes to species recovery through research, monitoring and analysis, providing NOAA managers and regional stakeholders the tools and information they need to craft effective regulations and develop sustainable plans for recovery.

Habitats to Support Sustainable Fisheries and Recovered Populations
Healthy oceans, coastal waters, and riverine habitats provide the foundation for aquatic resources used by a diversity of species and society. Protecting marine, estuarine and freshwater ecosystems that support these species relies on science to link habitat condition/processes and the biological effects of restoration actions. The NWFSC provides the habitat science behind many management actions taken by NOAA Fisheries and other natural resource agencies to protect and recover aquatic ecosystems and living marine resources. The NWFSC also maintains a longstanding focus on toxic chemical contaminants, as a foundation for regional and national research on pollution threats to fisheries and protected resources.

Research Infrastructure and support: The NWFSC headquarters is in Seattle, WA with five research stations strategically located in Washington and Oregon to meet mission needs for science to support management marine and anadromous species and their habitats. In 2010, NWFSC underwent a comprehensive review of facilities. The planning team combined NMFS headquarter staff, NWFSC staff and planning consultant representatives. A Northwest Science Facilities Strategic Plan was developed to guide NWFSC facilities development and address limitations of current facilities. The six recommendations actions include:

- Modernize the Fisheries Science Headquarters at either the University of Washington campus west of 15th Avenue NE or the existing Montlake site.
- Update Manchester to support Aquaculture Research and species recovery.
- Construct a Center for Puget Sound Science at Mukilteo.
- Invest in continuing collaborative research at Newport.
- Continue to support Fish Ecology research at Pasco. Evaluate the operational and financial ramifications of potential future divestment.
- Consolidate coast and estuary research in Astoria.

The current focus is exploring the strategic alignment with the University of Washington on benefits of co-location, furthering our relationship with Oregon State University on the ecology of the northern California Current by means of joint research at OSU's Hatfield Marine Science Center, Newport Oregon, and pursuing the final clearance of the transfer of the Mukilteo field station site from the Department of Defense to NOAA. Further progress on these program plans is contingent on funding.

An important regional transportation project will have direct impacts on the NWFSC research headquarters in Seattle, WA. The Seattle headquarters facility is located adjacent to the SR-520 transportation corridor that connects Seattle to the east side of Lake Washington. The SR-520 Bridge Replacement and High Occupancy Vehicle Program seeks to "enhance safety by replacing the aging floating bridge and keep the region moving with vital transit and roadway improvements throughout the corridor (http://www.wsdot.wa.gov/Projects/SR520Bridge/) ." The NWFSC goal is to help this important regional priority move forward while maintaining our ability to do cutting-edge science.

Background

National Priorities for Ocean Research

NOAA Fisheries describes its mission as "responsible for the management, conservation and protection of living marine resources within the United States Exclusive Economic Zone. NOAA Fisheries also plays a supportive and advisory role in the management of living marine resources in coastal areas under state jurisdiction, provides scientific and policy leadership in the international arena and implements international conservation and management measures as appropriate. " Many factors, both natural and anthropogenic, affect populations of fish, invertebrates, marine mammals and marine ecosystems. Although natural factors cannot be controlled, and many human-caused factors are outside the control of NOAA Fisheries, the agency collects and maintains scientific information to inform and advise policymakers and managers. Understanding and predicting the health and productivity of marine ecosystems is critical to our stewardship mission. The NWFSC Strategic Science Plan is aligned with this mission and with the priorities of the Administration.

In February 2012, Dr. Jane Lubchenco, Undersecretary of Commerce for Oceans and Atmosphere, issued her Annual Guidance Memo calling on NOAA to focus on the following areas:

1. **Climate:** Through collaborative strategies, continue to advance the observations, modeling, and research necessary to understand climate change and its impacts; and transition mature climate science into regular, reliable, and relevant information services;

2. **Weather:** NOAA will build a "Weather-ready" nation by preserving and improving its ability to provide timely and accurate forecasts and warnings for the protection of life and property through science, technology, infrastructure improvements and collaborative efforts with partners;

3. **Oceans:** NOAA will advance our efforts to ensure the long-term sustainability of marine fisheries and recovery of protected species and their habitats;

4. **Coasts:** NOAA will deliver integrated data, information, products, and services needed to support resilient coastal communities and economies;

"We have a stewardship responsibility to maintain healthy, resilient, and sustainable oceans, coasts, and Great Lakes resources for the benefit of this and future generations. Yet, the oceans, coasts, and Great Lakes are subject to substantial pressures and face significant environmental challenges. Challenges include water pollution and degraded coastal water quality caused by industrial and commercial activities both onshore and offshore, habitat loss, fishing impacts, invasive species, disease, rising sea levels, and ocean acidification. Oceans both influence and are affected by climate change. They not only affect climate processes but they are also under stress from the impacts of climate change. Renewable energy, shipping, and aquaculture are also expected to place growing demands on ocean and Great Lakes resources."

- President Barack Obama

5. **Science and Technology:** NOAA will focus on developing systems-level understanding of ecosystems and phenomena—across missions and disciplines—with the goal of increasing the resilience of ecosystems, economies, and communities;

6. **Engagement:** NOAA will expand efforts to listen and respond to our customers' and stakeholders' concerns and better relate NOAA mission responsibilities and activities to those concerns; and

7. **Organization and Administration:** NOAA will further capitalize on recent initiatives to cut costs and improve effectiveness.

Role of the Northwest Fisheries Science Center

The NWFSC operates under the vision that "scientists at the Northwest Fisheries Science Center conduct leading-edge research and analyses that provide the foundation for management decisions to protect, recover, restore, and sustain ecosystems and living marine resources in the Pacific Northwest." NWFSC researchers are dedicated to producing scientific products that will strengthen decision-making at all levels, enhance socio-economic benefits, support sustainable resource use, and conserve biological diversity.

NWFSC Research Themes and Foci

Sustainable, safe and secure seafood for healthy populations and vibrant communities

1. Provide scientific support for setting annual catch limits and measure results of annual catch limit implementation
2. Support effective catch share management and evaluation
3. Provide scientific support to ensure safe seafood for healthy populations and characterize how human activities and climate affect risks from pathogens, chemical contaminants and biotoxins.
4. Develop research and technology to foster innovative and sustainable approaches to aquaculture.
5. Support collaborative community-based data collection, dissemination, and analysis for fishers, fisheries management, science, marketing, seafood safety, and education

Ecosystem approach to improve management of marine resources

6. Provide scientific support for the implementation of ecosystem-based management.
7. Describe the interaction between human activities, particularly harvest of marine resources, and ecosystem function.
8. Understand how climate influences ecosystem variability.
9. Characterize ecological interactions (e.g. predation, competition, parasitism, disease, etc.) within and among species.
10. Characterize the interaction between marine, freshwater and terrestrial ecosystem components.
11. Assess ecosystem status and trends.

Recovery and rebuilding of marine and coastal species

12. Describe the relationships between human activities and species recovery, rebuilding and sustainability.
13. Characterize the population biology of species, and develop and improve methods for predicting the status of populations.
14. Develop methods to use physiological, biological and behavioral information to predict population-level processes.
15. Evaluate the effects of artificial propagation on recovery, rebuilding and sustainability of marine and anadromous species.

Habitats to Support Sustainable Fisheries and Recovered Populations

16. Characterize relationships between habitat and ecosystem processes, climate variation, and the viability of organisms.
17. Characterize the interaction of human use and habitat distribution, quantity and quality.
18. Assess the impacts of toxic chemicals and other pollutants across biological scales, and identify pollution reduction strategies that improve habitat quality.
19. Develop effective and efficient habitat restoration and conservation techniques.

NOAA FISHERIES

Research Theme I

Pike Place Market, Seattle WA. (Photo Su Kim, NWFSC)

Research Theme I: Sustainable, safe and secure seafood for healthy populations and vibrant communities

In the Pacific Northwest, much of the population lives at the coastal interface of terrestrial and marine ecosystems, with an increasing trend in the coming decades (e.g., 1.4 million more residents are predicted in the Puget Sound region by 2020). The ocean and coastal environments provide numerous benefits to humans, including nutritious seafood, various pharmaceuticals and natural products, and opportunities for a multitude of recreational and commercial activities.

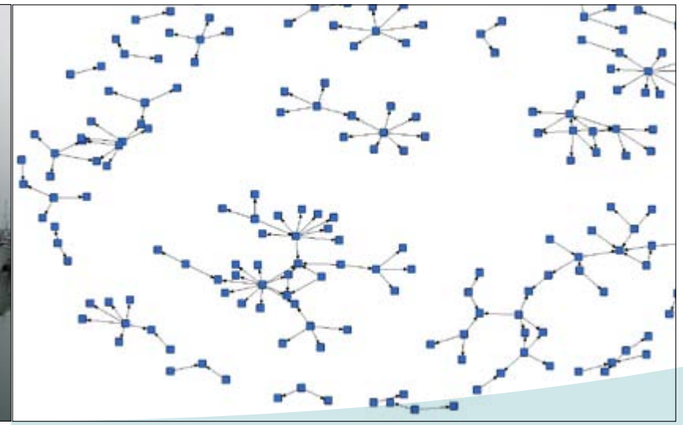
Fishing in ocean and coastal areas supports economically viable communities, feeds people around the world, and offers important recreational opportunities. Effective fisheries management provides economic opportunities and ensures the long-term sustainability of those fisheries and the habitats on which they depend; it is also highly dependent upon timely, accurate and reliable information about the current condition of stocks, prey species, habitats and human responses to management measures. Two of the research foci under this theme are improving the quality of available information for fisheries managers and supporting them in ensuring stock and ecosystem sustainability as well as limiting impacts on human communities from management measures.

There are other key management issues to providing safe and secure seafood. First, pathogens, toxins from harmful algal blooms (HABs) and chemical contaminants present in marine ecosystems pose significant risks to health of both humans and marine life. Critical gaps exist in our knowledge of what those risks are, how to forecast them, and identification of means to mitigate their impacts. NWFSC's research includes studies on ocean and climate factors that directly impact seafood safety through their effects on pathogens and HABs, and studies using sentinel or surrogate species to measure the impacts of chemical contaminants or other anthropogenic and natural stressors on human health. Second, aquaculture produces a significant proportion of seafood consumed globally. Aquaculture research explores a diversity of issues related to the culture of fish and shellfish for human consumption and for stock enhancement and restoration. Two research priorities listed below focus on aquaculture, pathogens, HABS, chemical contaminants and sentinel species.

Research Foci for Research Theme I

1. *Provide scientific support for setting annual catch limits and measure results of annual catch limit implementation.*
   Effective fisheries management is dependent upon reliable estimates of current stock status and projections of likely future status. Work in this area focuses on several key research components. The first goal is to improve stock assessments and applications. NWFSC stock assessment scientists are currently using and developing state-of-the-art data collection and assessment methods. Priority research in this area includes continuing improvement of existing methods, development of methods for data-limited species and making these high-end techniques readily available to assessment scientists around the world. A second priority is to improve data for stock assessments. Stock assessments rely on both fishery-dependent and fishery-independent information. NWFSC scientists are involved in designing and implementing surveys, improving and enhancing data collection methods, including developing advanced technologies for ocean sampling, and evaluating the results of those surveys. Annual surveys are conducted to collect data on targeted species, habitats and ecosystems; the data are vital inputs to mathematical models used to inform management decisions. Third, NWFSC scientists measure and estimate fishery-related mortality for by-caught and discarded species. Reliable estimates of the numbers and distribution of non-target species affected by the fishery is a critical component of effective fisheries and protected resource management in the short-term (within season management measures) and long-term (e.g. restricted area definition). Scientists develop and improve data collection for this purpose, as well as improve analytical methods for estimating this catch.

2. *Support effective catch share management and evaluation*
   Catch share programs use allocations of target and by-caught species to individuals, with the goal of improving the safety and profitability of the fishery while reducing environmental impacts, particularly with respect to bycatch. This type of Individual Transferable Quota program was implemented for the West Coast Groundfish fishery in 2011. While the catch share program itself is a management construct, evaluating its effects and providing key information about immediate harvest and bycatch status are science issues. Research to support this catch share program falls within four areas. First, identifying cost-effective monitoring systems is imperative. Currently, the West Coast groundfish fishery requires 100% observer coverage. Determining whether an electronic monitoring program that meets scientific, management, enforcement and fishery information needs and is cost-effective is a key priority. In collaboration with industry, states and fishers, NWFSC scientists are currently designing monitoring systems, evaluating their effectiveness and assessing trade-offs in information quality and costs for these programs. Second, catch share programs are designed to provide individual accountability and flexibility and increase the overall profitability of the fishery. Determining to what degree these goals are achieved, how changes are made and their impacts on fishing communities is a key element of improving management in the long-term. Third, NWFSC scientists are evaluating the biological, ecological and social impacts of the catch share program. As a result of increased flexibility, catch shares programs are also anticipated to alter human interactions with the ecosystem, in the timing of fishing activities, fishing intensity on at least some species, and potentially on the location of fishing activities. Any of these changes are likely to have cascading effects on the status of stocks and the systems upon which they depend. The NWFSC is actively working with NOAA and academic scientists to evaluate these effects. And last, it is important to improve data delivery systems for management. To provide the flexibility and accountability that a catch shares program promises, data must be available to fishers and managers in near-real-time. NWFSC scientists are working to improve existing database systems and add novel components allowing greater accessibility to data.



An example of a Pacific Groundfish Industry social network based on results of surveys and interviews with participants in WA, OR, and CA fisheries. Each point represents a person who works in the fishery. Each line represents a communication link between people sharing everyday information about the fishery. Social mapping allows for the identification of key resource informants and demonstrates how information is transferred within the fishery. (Photo Suzanne Russell, NWFSC)

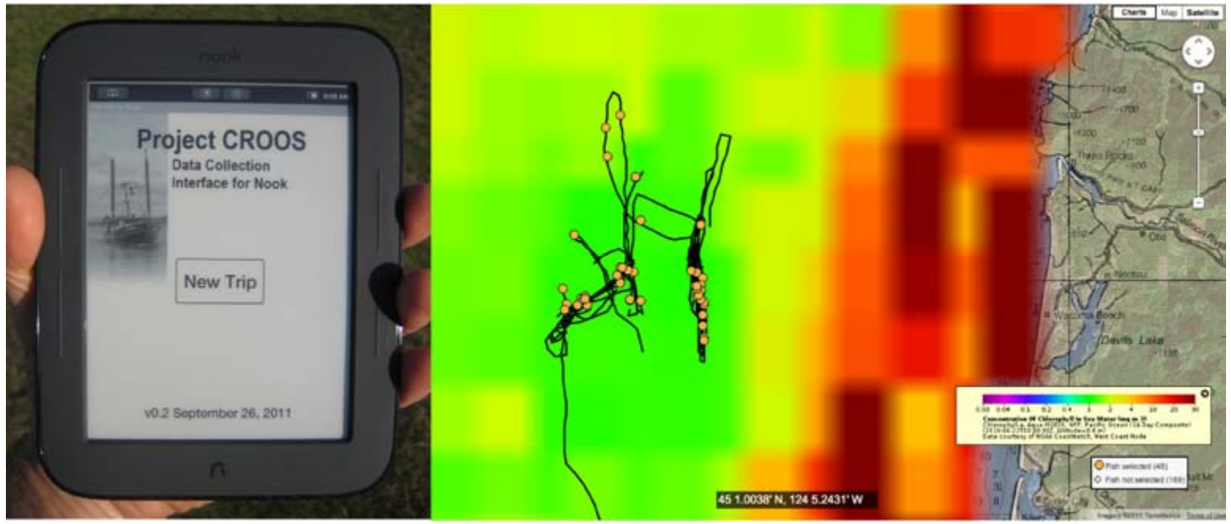
3. *Provide scientific support to ensure safe seafood for healthy populations and characterize how human activities and climate affect risks from pathogens, chemical contaminants and biotoxins.*
The availability of nutritious and safe seafood from marine ecosystems and aquaculture are essential to maintain and maximize human health. Even though fish are known to have a variety of health benefits, some seafood (wild or farmed) may contain levels of toxic compounds (e.g., chemical contaminants, pathogens, biotoxins) from a variety of human-related and natural sources that can pose health risks to humans, especially for those groups with high rates of seafood consumption. The development of novel methods and technologies to assess seafood safety and biological effects of these toxic compounds remains a priority for commercial, subsistence and recreational consumption of seafood. For example, several species (e.g., zebrafish, sea lions, shellfish) are excellent indicators of environmental stress and potential health threats to marine species and humans. These species can serve as informative animal models for investigations of the mechanisms of toxicity or disease processes. Specific research goals include (1) improve methods for monitoring for the presence of pathogens, toxins and contaminants in seafood products, (2) characterize the environmental and climate conditions that may be favorable for potential biotoxin and pathogen outbreaks, (3) develop technologies to remove chemical contaminants from fish feed and to enhance the nutritional content of aquaculture products, (4) develop a better understanding of the net economic and health benefits of seafood consumption balanced with the risk of exposure to pathogens, toxins and contaminants, and (5) develop new mechanistic animal models for the study of infectious diseases, as well as toxicological, physiological, and biochemical processes relevant to marine animal and human health.

4. *Develop research and technology to foster innovative and sustainable approaches to aquaculture.*
The NOAA Aquaculture Policy calls for enabling sustainable aquaculture that provides domestic jobs, products, and services and that is in harmony with healthy, productive, and resilient marine ecosystems. To achieve these goals, NWFSC's research examines scientific and technical issues to support aquaculture production. NWFSC research also considers potential impacts of aquaculture practices on the environment and on wild populations of fish and shellfish and methods for diminishing those impacts. Specific research objectives include (1) identify methods for reducing reliance on forage fish protein and oil in aquaculture feeds; this includes the evaluation of plant and microbe-based alternatives for fish meal and oil, because fishmeal and oil used in producing artificial fish diets is unsustainable and often a source of contaminants, (2) evaluate and model potential genetic impacts of aquaculture escapes on natural populations, (3) develop shellfish research that will support regional initiatives, such as the Washington Shellfish Initiative, especially native shellfish restoration and (4) develop new marine species for aquaculture and shore-based marine recirculating aquaculture systems.

A new, native shellfish hatchery is being designed to be located at the Manchester research station. This facility will establish a hatchery breeding program for native Olympia oysters (Ostrea lurida) to increase seed production that meets established genetic conservation guidelines. Construction is expected to start in late 2012 and be completed in 2013. The shellfish facility will bring shellfish culture activities back to the Manchester station and NWFSC after a 30-year absence.

Olympia oysters in Puget Sound.

5. *Support collaborative, community-based data collection, dissemination, and analysis for fishers, fisheries management, science, marketing, seafood safety, and education.*
Data are no longer the sole province of the agency. As technologies advance, fishers are collecting and analyzing fleet data in near real time. Data collected by fishers are used by the fishing community to reduce bycatch, allocate fishery impacts, and trace products through the processing and marketing system. Fisher-collected data, in combination with survey and oceanographic data, satellite remote sensing, economic data, and sociocultural data provide improved understanding of fish stocks, fishing, and the near-shore ecosystem. Collaborative efforts increase the quantity and quality of data available to the agency for scientific analysis, modeling, fishery management, and conservation. Through cooperation with the science and management agencies, the fishing community stands to gain more control and flexibility of their fishing operations, including the potential for improved economic efficiency. Increased availability of fisheries data creates opportunities for education and outreach both in the school system and to the general public. Further, well-informed local leaders conversant in the latest fishery issues will help garner local support and fisher buy-in for improved information sharing. The NWFSC will work with industry groups to improve distributed data collection, compilation, and distribution for multiple uses in fisheries, management, science, marketing, and education.



Nook(TM) e-reader adapted for fishermen to collect data at sea. The elnk screen is visible in full sunlight. Data can be transmitted to shore and viewed on the web portal within minutes. On the right, the fisherman's web portal (fp.fishtrax.org/portal) shows fish caught (orange dots) by an individual fisherman from June 15 to 30, 2010. The path fished is drawn as a black line. The background is satellite-measured chlorophyll concentrations from NOAA CoastWatch. Data displays like this are available to fishermen to help guide their fishing activities. A similar portal for the general public is also available.

NOAA FISHERIES

Research Theme II

Giant kelp. (Photo Claire Fackler, CINMS, NOAA)

Research Theme II: Ecosystem approach to improve management of marine resources

The California Current Large Marine Ecosystem (LME) spans the entire west coast of the US and supports a wide range of valuable marine resources. In addition, Puget Sound, the Columbia River estuary and countless smaller estuaries and inland freshwater ecosystems support salmon populations and provide biotic and abiotic inputs to marine ecosystems. The ability of these marine ecosystems to produce important products and services – fisheries, climate regulation, pollution control, energy production, transportation and recreation – depends on their integrity. Human impacts have led to degradation of ecosystems and complex management issues from competing sectors. Ensuring the resiliency and productivity of ecosystems will require understanding their structure, function, and vulnerability to anthropogenic actions. The ecosystem approach research theme builds upon science supporting current management efforts. This approach integrates scientific disciplines and accounts for interactions within and across ecosystems. Research foci emphasize the need to conduct a comprehensive assessment of ecosystem components and develop appropriate measurement indicators; characterize the linkages and interactions between physical processes, species, and human activities; and provide a basis to measure and predict ecosystem responses and socio-economic benefits and costs of management actions. The careful assessment of ecosystem indicators will form a sound scientific basis to shape management practices that are flexible and sensitive to changing conditions and new information. The NWFSC provides science support for moving resource management toward a more holistic, ecosystem-based strategy.

Research Foci for Research Theme II

6. *Provide scientific support for the implementation of ecosystem-based management.*
   Fisheries scientists and managers recognize the potential for ecosystem-based management to improve sustain the delivery of ecosystem goods and services, including sustainable fisheries resources. An Integrated Ecosystem Assessment (IEA) is one approach that examines all available information on relevant physical, chemical, ecological and human processes in relation to specified ecosystem management objectives. IEAs provide an efficient, transparent means of summarizing the status of ecosystem components, screening and prioritizing potential risks, and evaluating alternative management strategies against a backdrop of environmental variability. To perform IEAs of major ecosystems will require development of project components, including new and existing data, to develop a suite of indicators that characterize the ecosystem. Careful assessment of ecosystem indicators will provide a powerful means for assessing management efficacy and a basis for adapting and improving management practices. A major focus will be to produce the initial IEA of the California Current LME and then provide annual updates.

Using a state-of-the-art facility, the NWFSC is leading efforts to understand the biological and ecological impacts of ocean acidification throughout the West Coast. The facility is being used to examine multiple stressors (e.g., CO2, pH, temperature, light, feeding rate) for Puget Sound species of economic value, ecological importance, or conservation concern. These animals are grown in conditions that mimic pre-industrial, current, and future ocean carbon dioxide levels to observe changes in animal growth, survival and behavior. (left)

7. *Describe the interaction between human activities, particularly harvest of marine resources, and ecosystem function.*
   Humans are an integral component of ecosystems. These ecosystems provide goods and services such as fish and seafood harvests, but these activities and others such as habitat alteration, pollution, and ocean acidification, can have strong impacts. Understanding the nature of these interactions will require observational and experimental studies aimed at identifying ecosystem-level responses to human activities, both individually and cumulatively, as well as human responses to ecosystem changes. Modeling spatial choices for harvesting and other human activities that are affected by ecosystem integrity, for example, can support a better understanding of the effects of ecosystem-based management actions.

8. *Understand how climate influences ecosystem vulnerability and variability.*
   Effective ecosystem management will require an understanding of how climate variability and climate change will alter riverine, estuarine, and marine habitats and consequently how this will affect ecosystem status, function and recovery. Key research elements include better understanding of historical ecological variability through traditional (i.e., indigenous) sources, exploring the vulnerability of key species and biotic communities to expected habitat changes, including decreasing stream flow, increased flood frequency, increasing stream temperature, sea level rise, ocean acidification, shifts in ocean currents, and changed frequency and extent of deoxygenated zones. A secondary goal is to improve understanding of how ecosystems respond to year-to-year and decadal climate variability. Achieving these research goals will provide NOAA and state and local governments with the knowledge and tools needed to incorporate climate change and variability into management of living marine resources.

A five step process for IEAs. The bold arrow from the monitoring box to the risk analysis box indicates that analyses will be updated as more data become available. The dotted lines to the other boxes indicate that these steps may need revisiting as more data are collected. (below)

NOAA FISHERIES

Southern Resident killer whale feeding on a Chinook salmon. (Photo Brad Hanson, NWFSC)

9. *Characterize ecological interactions (e.g. predation, competition, parasitism, disease, etc.) within and among species.*
   Predator-prey interactions, inter- and intra-specific competition, and parasites and pathogens influence the survival, growth, and reproductive success of anadromous and marine fishes, marine mammals and other marine organisms. Moreover, anthropogenic stressors, such as pollution and fishing, can influence these interactions. Because of the complex nature of these interactions, addressing questions about ecological interactions will require novel field and laboratory studies and analyses. This includes ecosystem models, use of innovative technologies (e.g., otolith microchemistry and stable isotopes), integration of sample collection efforts with those of the Ocean Observing System entities on the west coast, and quantifying interactions among environmental stressors, species behavior and ecosystem processes.

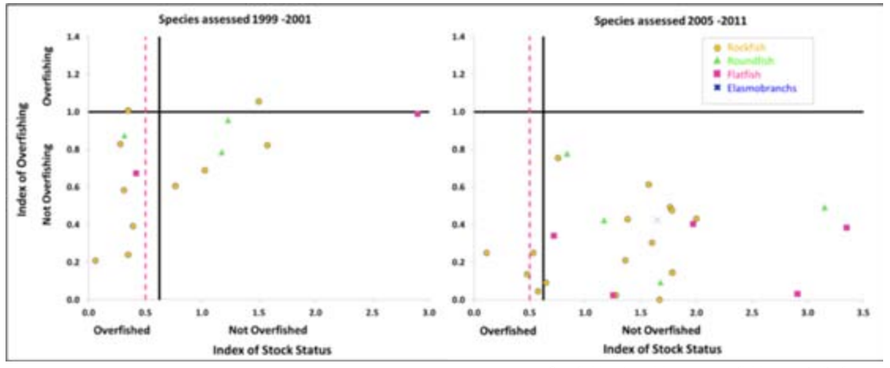
10. *Characterize the interaction between marine, freshwater and terrestrial ecosystem components.*
    Although many species migrate between connected aquatic, marine, estuarine and freshwater environments they are commonly studied and managed as separate ecosystems. Environmental conditions in both marine and freshwater areas are strongly influenced by flows of water, sediment, organic matter and nutrients among ecosystems. Moreover, many threats (e.g., pollution, habitat loss, climate change, etc.) to marine organisms cross land-sea boundaries. Successful management of aquatic systems thus requires an understanding of linkages among ecosystems, including study of how specific habitats (e.g., headwaters, floodplains, submerged aquatic vegetation, nearshore zones, plumes and frontal regions) contribute to the productivity and capacity of ecosystems, and how to prioritize ecosystem protection or restoration within the context of the entire freshwater-estuarine-marine ecosystem.

11. *Assess ecosystem status and trends*
    Tracking the status of ecosystems across time and space is data intensive as it necessitates evaluating a broad range of trophic levels and environmental conditions from pre-European times to the present. Because ecosystems vary across space and time, the NWFSC must maintain a research focus on the design and implementation of monitoring programs that are capable of capturing this variability. Key research elements are the development and application of novel survey designs, the development of information rich metrics and indicators, and the development of novel spatio-temporal decision support models to facilitate the use of monitoring data in science based decision making. Long-term monitoring program design should be integrated with the development of ecosystem models and indicators to ensure that critical data are collected to support these efforts. An important management goal is the ability to quickly detect important changes in the state of ecosystems (e.g., presence of an invasive species) such that preventative actions can be taken as soon as possible; thus, key management questions and uncertainties should be identified as the structure of monitoring program design to facilitate the decision-making process. It is imperative that the NWFSC's monitoring science strengths be applied to the design of ecosystem monitoring programs for species (e.g., salmon, rockfish) and ecosystems so that such programs are strategically designed to maximize useable information and minimize cost and effort.

The catch from one 15-minute tow during the 2013 West Coast Groundfish Bottom Trawl Survey. (Photo Keith L. Bosley, NWFSC)

Research Theme III: Recovery and rebuilding of marine and coastal species

An important part of NOAA Fisheries' mandate is to increase the abundance of depleted species and stocks. This mandate comes from multiple sources, including the Magnuson-Stevens Act's requirement to rebuild overfished fishery stocks, the Marine Mammal Protection Act's charge of protecting marine mammals and turtles, and the Endangered Species Act's requirement to protect threatened and endangered species of all types. The Pacific Northwest is home to several iconic endangered species, including Pacific salmon and killer whales, and also to some less well known species such as Pacific eulachon (a species of smelt) and three species of Puget Sound rockfish. Ten additional fish, shark and mollusk species are classified as "species of concern". In addition, seven West Coast marine fish stocks are classified as "overfished" under the Magnuson-Stevens Act. Humans depend on these at risk species for sustenance, other economic benefits, and ways of life, thus achieving recovery and rebuilding of these species is a high priority for the region and the nation. The NWFSC contributes to species recovery through research, monitoring and analysis that gives NOAA managers and regional stakeholders the tools and information they need to craft effective regulations and develop sustainable plans for recovery.



A comparison of overfishing (y-axis) and status (x-axis) for groundfish stocks assessed during two periods (1999-2001; 2005-2011). Recent assessment of additional stocks revealed fewer are in an overfished condition, which reflects the agency's success in rebuilding U.S. Pacific groundfish stocks. Also, fisheries harvested a much smaller fraction of the maximum sustainable yield compared to the earlier period, a difference due in part to management efforts to rebuild stocks to target levels.

Stock status compares the most recent measure of spawning output (or a proxy) to the first year of spawning output (or a proxy). For each stock, the target is for the Index of Stock Status value (x-axis) to be greater than or equal to 1. Values of the Stock Status Index below the limits of 0.625 (vertical black lines) for most groundfish, or 0.5 (dashed pink lines) for flatfish, indicate that the stock was in an overfished condition. The Index of Overfishing (y-axis) compares fishing mortality from all sources with the catch limits published for those individual species. These "overfishing" catch limits (horizontal black lines at 1.0) are set at a level equal to Maximum Sustainable Yield (or a proxy); exceeding those levels is considered overfishing. In addition, there were seven assessed stocks not included in the figure because they lacked fishery status measures. None were below the status limit.

Research Foci for Research Theme III

12. *Describe the relationships between human activities and species recovery, rebuilding and sustainability.*
    Human activities play a major role in determining the status of species and stocks. Rebuilding and recovery therefore need to address how these activities affect their status. At the NWFSC, biophysical modeling is used to link specific human activities such as land use and pollution to habitat conditions, and then to link these conditions and other activities to particular life stages. These models can be used to quantitatively assess how human activities influence species abundance, productivity, distribution and diversity. Not surprisingly, altering human activities in some way is often necessary for species or stock recovery and rebuilding. It is therefore important to understand the socio-economic effects of alternative management structures. Gathering data on their economic costs and social impacts helps identify actions that are cost-effective. These actions will need to be resilient to potential changes in climate throughout the region. Research on how humans react to management strategies helps policy makers avoid those that lead to unintended consequences that can hinder rather than help recovery.

13. *Characterize the population biology of species, and develop and improve methods for predicting the status of populations.*
    To evaluate species status and recovery, it is necessary to understand key aspects of the population biology of the species in question. This includes basic information on abundance, age structure, recruitment, spatial distribution, life history and how the species interacts with its ecosystem. For some recovering species, including most overfished groundfish stocks, many ESA-listed Pacific salmon stocks, and high profile species such as Southern Resident killer whales, this basic information is often reasonably well understood. For other recovering species, such as Pacific eulachon and some ESA-listed rockfish species, even basic information (e.g. stock abundance) is unknown. Even for well-studied species, key information on survival rates for critical life stages and how the environment affects these vital rates is lacking. Without basic information on species dynamics, achieving other goals such as quantifying relationships between human activities and species recovery or even knowing if species recovery goals are being met will not be successful. The NWFSC, in partnership with regional stakeholders, including states, tribes and industry, is conducting research to collect and monitor critical demographic information for recovering species.

Lingcod. (photo Kelly Andrews)

14. *Develop methods to use physiological, biological and behavioral information of organisms to predict population-level processes.*
    Understanding the biological processes occurring within organisms is a powerful way of understanding how environmental changes affect those organisms. Genetics, developmental, physiological and behavioral studies all provide important information for effective species recovery and rebuilding. Integrating this information into models is vital to predict how populations will respond to natural or human perturbations, and to assess the constraints to stock rebuilding efforts. For example, data on thermal tolerance and physiological responses to temperature can be used to explore changes caused by shifts in climate on reproductive behavior and productivity, viability, movement, habitat selection, and population dynamics. Similarly, data on contaminants that impact physiological processes (immune system, growth, development, reproduction, and general health) are critical in determining how these compounds affect population dynamics. Data on biological responses of organisms to ocean acidification are useful for understanding how acidification may affect individual development and survival. The NWFSC collects such information for several species that are of concern, targets of fisheries or otherwise important for overall ecosystem function. NWFSC scientists will continue to expand current efforts and develop methods to incorporate physiological, biological and behavioral data into population models in order to predict population-level processes from these individual level data.

The Elwha Dam (upper left, photo Lighthawk) removal began in the fall of 2011 and was completed in spring 2012 (upper right, photo John McMillian). A second dam on the Elwha River, the Glines Canyon Dam, will be removed by 2013. NWFSC has been continuously gathering information to understand the impacts that the removal of these dams will have on the Elwha River and adjacent marine habitat (lower left, photo Lighthawk & Neal Chism), the salmon populations, and local, regional and national communities. In conjunction with its partners, NWFSC is conducting long-term monitoring in the lower Elwha River to evaluate habitat conditions, fish presence (steelhead, lower right, photo John McMillian), and habitat use and distribution.

15. *Evaluate the effects of artificial propagation on recovery, rebuilding and sustainability of marine and anadromous species.*
    Artificial propagation has the potential to provide benefits both to species recovery and to seafood sustainability. Artificial propagation also poses risks to wild species and ecosystems. In the past, the use of artificial propagation has been an important risk factor for several threatened and endangered species, particularly Pacific salmon. Assessing the effects of artificial propagation is complicated by the fact that programs vary widely in size, rearing practices, and goals. The NWFSC conducts critical research on the influence of artificial propagation on population dynamics, growth rate, ecology of infectious disease, and the evolutionary fitness of wild fish and other marine organisms. Results of this research are needed to support the recovery of fish populations and have been especially valuable in providing critical information for recent, larger scale habitat restoration activities such as the Elwha Dam removal. NWFSC will continue to conduct science that informs the discussion about whether to allow fish to recolonize naturally after barrier removal, or to supplement populations with hatchery fish and on the impacts of aquaculture on fishing pressure and practices, and on the surrounding environment and ecosystem.

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Research Theme IV

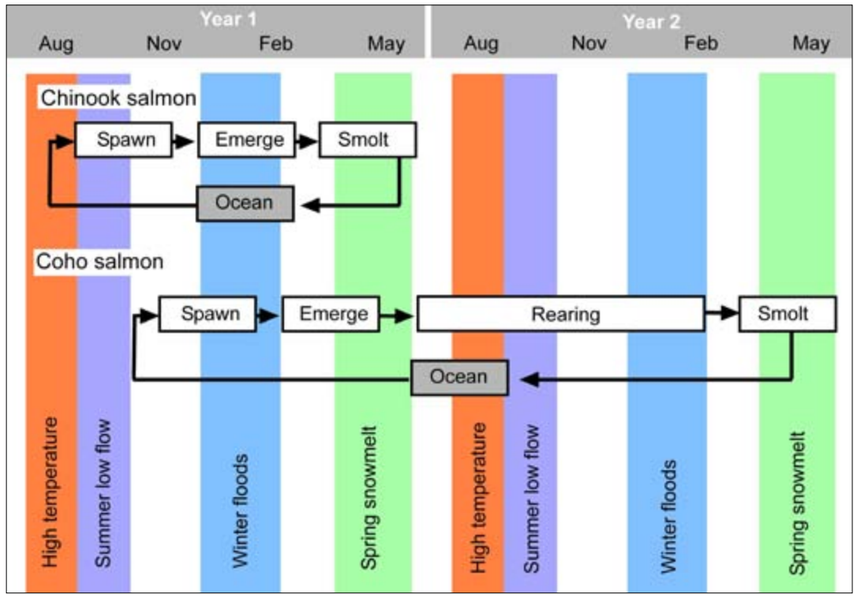
Primnoa pacifica providing habitat for rockfish. Washington, Olympic Coast NMS. (Photo Ed Bowlby/NOAA)

Research Theme IV: Habitats to Support Sustainable Fisheries and Recovered Populations

Healthy oceans and natural coastal and riverine habitats provide the foundation for aquatic resources that society depends on. To manage west coast marine, estuarine and freshwater ecosystems in a sustainable fashion, habitat conditions must be linked to their biological effects on species at the nested scales of the individual, population, community and ecosystem. More regional information is needed about physical, chemical and biological habitat features that are important to species by location, extent, persistence, and condition. Furthermore, NOAA Fisheries and other natural resource managers must understand what long-term processes form and sustain riparian, riverine, estuarine, and ocean environments. These processes include the transport of sediment, water, and organic material from terrestrial areas through streams, to rivers, through estuaries, and into the ocean, or actions from extraction that alters benthic marine habitat. They also include the impacts of toxics and other forms of pollution from land-based sources, oil spills, and historical human activities. Research at the NWFSC provides the basis for many of the management actions taken by NOAA Fisheries and other natural resource agencies as they strive to protect and recover aquatic ecosystems and marine and andromous species. Research foci include: the linkage of habitat features to life-stage survival, growth and productivity of organisms; mapping the footprint of human activities and their impacts to species of interest; identifying and minimizing the harmful effects of pollution on organismal health and habitat-forming processes; and developing restoration techniques that are compatible with large-scale processes to create diverse and dynamic habitats. As with other research themes, the development of metrics and evaluation models are needed to identify trends, improve predictive capability, and develop sustainable management approaches to habitat.

Research Foci for Research Theme IV

16. *Characterize relationships between ecosystem processes, climate variability and change, habitat and the viability of organisms.*
    Developing effective conservation and restoration strategies for species or populations requires a clear understanding of how ecosystem processes and climate change will influence the viability of organisms in the future. Key research needs include (1) evaluating the vulnerability of organisms and ecosystems to climate change and human impacts (e.g., fishing, pollution, land use), and (2) devising adaptation strategies that will help achieve conservation goals despite climate change and increasing human pressures. Understanding how climate change or trends in human impacts might influence organisms is based on an understanding of linkages between ecosystem processes, habitat conditions, and abundance, survival or demographics of organisms. This necessitates modeling influences of ecosystem processes on habitats and species, or developing models to examine influences of human pressures on population or ecosystem dynamics. With this foundation, vulnerability assessments can focus on understanding how interactions between climate change and human impacts influence vulnerability of species or populations. Adaptation strategies require knowledge of current conservation needs, predictions of how those needs might change as a result of climate change or future human impacts, and assessments of the robustness of alternative conservation strategies or techniques to climate trends.



Overlap of salmon life history stages and timing of climate change effects on stream flow and temperature will determine effects of climate change on salmon viability. This example shows how two different species will interact with predicted climate change effects in snowmelt-dominated rivers of the Pacific Northwest.

17. *Characterize the interaction of human use and habitat distribution, quantity and quality.*
    The ability to define the state of an ecosystem requires insight into the natural processes within habitats, and how anthropogenic interactions with these processes can alter ecosystems and marine organisms. A wide diversity of human activities -- land use and water withdrawals, industrialization and dredging, fishing practices and climate change (e.g., ocean acidification) -- directly and indirectly impact critical freshwater, estuarine, and marine habitats. To best manage west coast marine, estuarine and freshwater habitats in a sustainable fashion, it is necessary to map the spatial and temporal footprint of human impacts and review their potential biological impact on each species of interest. Measurement parameters will be developed to determine the full range of human impacts using spatial data and improved habitat classification.

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18. *Assess the impacts of toxic chemicals and other pollutants across biological scales, and identify pollution reduction strategies that improve habitat quality.*
The NWFSC has been at the forefront of marine pollution research for more than four decades, providing science support for several major events, including the Exxon Valdez oil spill, Hurricane Katrina, and the Deepwater Horizon disaster. Land-based sources of pollution are an increasingly important threat to NOAA trust resources, and NWFSC science is evolving to fill priority information gaps at the regional and national scales. This includes targeted research on major classes of contaminants (e.g., crude oil, pesticides, metals, pharmaceuticals and other chemicals of emerging concern); surveillance monitoring to assess the exposure, health and status of species in polluted habitats; exposure; monitoring to assess the success of habitat restoration efforts; and research to evaluate the effectiveness of new green infrastructure technologies. Ongoing efforts span all biological scales, from molecular mechanisms of toxicity to population and community-level responses.

19. *Develop effective and efficient habitat restoration and conservation techniques.*
Maintaining and re-establishing viability and sustainability of living marine resources requires conservation and rehabilitation or restoration of habitats upon which species depend. Common habitat restoration approaches and tech-niques often presume that habitats are static features of the environment, and that creation of stable habitats is a desirable restoration strategy. However, riverine, nearshore, and marine habitats are created and sustained by dynamic landscape, climatic, and oceanographic processes and biota are adapted to changing habitats that are within the range of natural variability. Hence, current restoration strategies often have limited success, in part because they fail to recognize larger scale processes that drive habitat change, and in part because they fail to recognize intrinsic habitat potential of individual restoration sites. The main goals of this research focus are to: improve understanding of how large-scale processes create diverse and dynamic habitats that support marine and anadromous species, better understand how human activities alter habitat-forming processes and habitats, develop new restoration techniques that are compatible with sustainable habitat-forming processes, and understand the variety of actions needed to adequately conserve intact critical habitats. In addition, NWFSC's research will improve understanding of how new and existing habitat restoration and protection techniques affect fish and habitat at multiple scales (i.e., reach, watershed, Evolutionarily Significant Unit).

Salmon habitats in the shrub-steppe region of the Pacific Northwest have been dramatically altered by past land use activities, resulting in entrenched channels with little floodplain or riparian vegetation, low summer flows, and high temperatures. New techniques to encourage beaver recolonization in specific locations help to increase groundwater levels, restore summer stream flows, and reduce stream temperatures for salmon. (Photos Tim Beechie, NWFSC and Kent Miller, USNPS)

Research Infrastructure & Support

Elwha River. (Photo Ruth Howell), NWFSC)

Research infrastructure and support

The NWFSC research activities require the active development and improvement of Center infrastructure and support capabilities. This section briefly describes the tools, facilities, and support staff needed to enable high-priority research.

Infrastructure: The NWFSC maintains the infrastructure for critical data management functions, laboratory facilities, field sampling, and administrative activities

The NWFSC, with its headquarters in Seattle, WA and five research research stations in Washington and Oregon, is home to more than 400 scientists and staff. The NWFSC headquarters houses the Office of the Science Director, as well as senior leadership (e.g., Directors, Program Managers) and staff for its five divisions: Conservation Biology; Environmental Conservation; Fish Ecology; Fishery Resource Analysis and Monitoring; Resource Enhancement & Utilization Technologies; and Operations, Management, and Information. The management structure of the NWFSC follows the "Hub and Spoke" paradigm, where the organization is arranged like a wheel in which management direction moves along spokes to its research stations that are connected to management at its hub. The Office of the Science Director, as well as the Divisions' Directors (i.e., the hub) provides overall leadership and coordination for the Center's science programs and ensures that adequate resources are available to its research Stations (i.e., the spokes of the wheel) to accomplish research priorities and that the Center's science is responsive to regional and national management needs. Each of the NWFSC's research stations provides a unique capability and optimized access to the major habitat types and species of study in the Pacific Northwest.

Research Stations:

- ***Manchester (WA).*** Manchester houses the largest marine net-pen research complex on the west coast, as well as saltwater systems and unique salmon and marine fish aquaculture facilities. Major areas of study at Manchester include research on aquaculture technologies, conservation hatcheries, captive broodstocks, stock enhancement, fish genetics and behavior, and PIT-tag technology.

- ***Mukilteo (WA).*** Located on the shores of Puget Sound, Mukilteo has a high-quality seawater system as well as specialized laboratories and equipment for studying the effects of toxic substances on marine and anadromous species. Major areas of study at Mukilteo include the rearing of marine flatfish and juvenile salmon for population studies and understanding the lifecycle of marine species and investigating the impacts of toxins and pollutants on living marine resources.

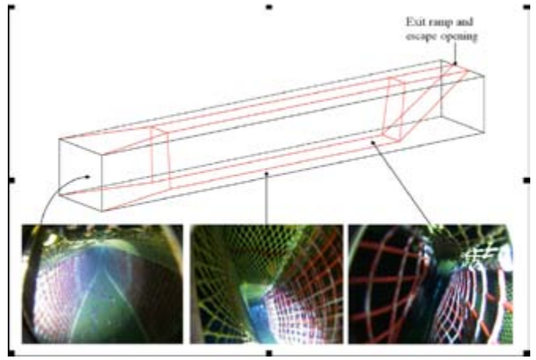
- ***Pasco (WA).*** Pasco is located on the Columbia River. Scientists at this station are engaged primarily with research on the migration and survival of anadromous fish through the Columbia River hydroelectric system. Pasco has a unique fabrication shop that enables scientists to quickly build and modify research equipment to support a wide range of fish passage, migration, and habitat research.

- ***Newport (OR).*** With its proximity to the Pacific Ocean and the new Marine Operations Center – Pacific, Newport is a hub for collaborative and ocean-based research. Major areas of study at Newport include surveying Pacific groundfish, identifying essential fish habitat, investigating fish disease, and studying the links between the ocean food web and climate change and variability.

- ***Point Adams (OR).*** Point Adams, at the mouth of the Columbia River, provides an ideal site for studying estuarine and near-ocean habitats. Major areas of study at Point Adams include understanding the estuarine ecology of juvenile salmon and evaluating the role of the Columbia River Plume as transition habitat for juvenile salmon between fresh and salt water.

Infrastructure: Current Capabilities and Needs

Implementing research priorities will require the active development and improvement of Center capabilities in several areas: (1) technologies that allow scientists to observe and analyze ocean, estuarine and freshwater environments; (2) models to evaluate alternative scenarios and effects; and (3) targeted changes in the data management, laboratory facilities, and field sampling infrastructure of the Center. In addition, the NWFSC realizes the importance of communicating its science to other scientists, decision-makers, and the public to increase awareness and support for the Center's work, foster understanding and use of Center's information, products, and services, as well as improve stewardship of coastal and marine species and their habitat. Last, NWFSC has been working with NMFS HQ and a planning team to develop a Facilities Strategic Plan that identifies the specific steps to meet our future research needs.



Schematic diagram of the flexible sorting grate designed to reduce rockfish bycatch in the Pacific hake fishery (top); aft view of the forward portion of the excluder where fish enter and encounter the device (bottom left image); forward view of the space where fish would enter after passing through the port panel of the vertical sorting grate and move aft towards the codend (middle image); forward view of the space where fish unable to pass through the sorting grate are forced out an exit ramp (bottom right image). The concept of this design is that fish smaller than the sorting grate openings (i.e. Pacific hake) will pass through the grate openings and be retained, whereas fish greater than the sorting grate openings (i.e. rockfishes) will be excluded from the trawl out an exit ramp.

1. **Technologies:** Ocean environments and the organisms that inhabit them are notoriously challenging to observe –the scales are large, the organisms are often fragile, cryptic or unknown, and the habitat is a demanding and expensive one for humans to occupy for prolonged periods of time. Technology that enables us to gain information remotely about oceanographic or other environmental conditions and about organisms across wide areas or in inaccessible habitats is a high priority. Other key technologies include those that allow us to understand the interaction between organisms of interest, their habitats and humans.

   - ***Observational systems and technologies*** ranging from small scale nets with towed cameras and acoustics, or animals instrumented with archival tags, to large-scale ocean observation systems, remote sensing (satellites, multi-beam, LIDAR, hyperspectral imagery, etc.), and remote and autonomous underwater vehicles facilitate the observation and mapping of ocean conditions at local to ecosystem scales. As sensing and communications technologies improve, new opportunities for distributed direct measurements will emerge. A combination of measurement and observation across scales are needed to ground-truth remote sensing data. These can then provide links between basin-scale physical and biological oceanography and the processes influencing local population dynamics and stock status.

   - ***Tagging and remote sensing technologies for individual organisms*** have progressed rapidly over the past several decades as the power of computers has increased, electronic components have decreased in size, and the ability to detect signals remotely has increased. The ability to detect and identify individual animals greatly enhances the ability to track movement, survival rates and other demographic and behavioral information. These data are needed to make decisions on altering management strategies for protecting listed stocks.

   - ***Population structure and patterns of movement*** can be determined by recent advances in genetic techniques, isotopes, and the identification of parasites. Improved sampling and throughput technologies can make significant contributions toward this goal. For instance, such technologies could allow observers to take thousands of genetic samples on boats. Data from those samples would significantly improve our ability to delineate stocks.

   - ***Landed catch, bycatch and discard*** has not been systematically monitored for some West Coast fisheries until recently. The West Coast Groundfish Observer Program (WCGOP) was established in 2001 to improve estimates of total catch and discard in west coast fisheries. The program deploys observers and collects at-sea data from limited-entry trawl and fixed gear fleets as well as from open access, nearshore, prawn, and shrimp fleets. An integrated electronic recording system for fishticket and logbook information for the Pacific coast would vastly improve the ability to track groundfish catches in season and to produce real-time estimates of landings and

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discard needed for timely management decision-making. In addition, NWFSC has developed two autonomous underwater video camera systems for filming commercial fishing gear and fish behavior during fishing operations. The purpose of these video camera systems is to provide trawl and fixed gear fishermen with equipment for evaluating industry-designed approaches to reduce bycatch and reduce impacts to benthic habitats.

- ***Geographically or spatially linked analysis and interpretation:*** Marine and freshwater research efforts increasingly rely on large geospatial data sets to address issues such as individual and population-level movement patterns, climate change effects on stream flows, ocean circulation patterns, and patterns of current and future land use. Maintaining up-to-date GIS capabilities, including software, databases and support staff, will be a critical element of conducting the landscape (and oceanscape) scale analyses that contribute to multiple goals.

- ***Socio-economic surveys*** are the primary means of collecting information and data used to describe the interactions between humans and living marine resources. Two important policy themes for socio-economic analysis are commercial and recreational fisheries, and conservation and ecosystem management.

- ***Bioinformatics*** include advances in genomic technologies; sensors that can be used for the rapid detection of pathogens, harmful algae, and toxins; and associated instrumentation. Molecular techniques that have been used to identify species and stock structure can also be used to assess gene expression patterns in the assessment of ecosystem function. Development of shared computational bioinformatics tools requires hardware, software and personnel with specific expertise. Presently the NWFSC has hardware and software for a bioinformatics core facility. Personnel with specific expertise in bioinformatics are needed.

2. **Models and the Data to Support Them:** Modeling provides a framework in which to describe a system in detail or in general, to evaluate the effects of alternative actions, and to characterize the sensitivity of a system to perturbations – all of which are essential for effective management. It is critical, however, that these models are supplemented by experiments, directed observational studies and other research efforts to develop the data to establish parameters and evaluate the models. Several types of models are being used or developed at the Center:

   - ***Socio-economic models*** are necessary to measure the benefits provided by natural resources, and how those benefits may changes as resource flows change. Economic valuation and behavioral models are needed to evaluate both use and non-use values, as well as regional economy, community and social impacts. These models will be linked to biological and ecological models of habitat distribution, quantity and quality.

   - ***Risk assessment models*** attempt to analyze biological information in the face of limited data, and are limited by the difficulty of capturing biological complexity through models with many parameters. Research is needed to incorporate additional biological information into simple models, and to develop methods for incorporating or specifying uncertainties.

   - ***Population dynamic models*** can be quite sophisticated, but substantial improvement in their utility can be achieved by developing ways of including information on spatial dynamics, the role of size and age composition in population demographics, and demographic and environmental stochasticity. At the ecosystem level, forecasting these impacts requires understanding complex dynamics controlling: 1) productivity of populations within various trophic levels, 2) predator-prey interactions, 3) connectedness of sub-populations, 4) impacts of natural climate variation and change, and 5) anthropogenic pressures.

   - ***Life cycle models*** are useful to translate changes in life-stage specific demographic rates (survival, capacity, and fecundity) in to changes in population viability. They are particularly useful to express the predicted benefits of mitigation actions across the life cycle in the context of other population's drivers including climate variability and change.

   - ***Evolutionary models*** are valuable for analyzing population dynamics of, and genetically-based changes in, exploited species or key components of disturbed ecosystems. Evolutionary approaches to this problem will link multivariate genetic models of life history variation to analyses of population dynamics and viability.

   - ***Models to support ecosystem approaches*** *to management* are being developed and include: 1) models aimed at prioritizing sites for conservation, 2) data-driven statistical models that estimate population or community dynamics, and 3) food web simulations.

   - ***Models treating habitats and landscapes*** contribute to effective recovery planning by analyzing how habitat restoration actions will affect population viability and sustainability. Few models are available to simulate how natural processes form and sustain habitat. Integration of data on the quantity, quality and spatial distribution of habitat can improve the predictive powers of assessment models and guide fishery management.

   - ***Designation and delineation models*** are being developed in response to the Magnuson- Stevens Fishery Conservation and Management Act requirement that regional fishery management councils describe Essential Fish Habitat (EFH) in their fishery management plans. Impacts on essential habitat from fishing activities other activities must be minimized. The models support National Marine Fisheries Service managers when they work with other agencies and the Pacific Fishery Management Council to modify activities that might harm EFH.

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- ***Integrated modeling approaches*** overcome many of the limitations described above and achieve the crucial goal of integrating physical, chemical, ecological, and fisheries dynamics in a three-dimensional, spatially explicit domain. In these models, ecosystem dynamics are represented by spatially explicit sub-models that simulate hydrographic processes (light- and temperature-driven fluxes of water and nutrients), biogeochemical factors driving primary production, and food web relations among functional groups. These models represent key exploited species at the level of detail necessary to evaluate direct effects of fishing, and they also represent other anthropogenic and climate impacts on the ecosystem as a whole.

3. **Infrastructure:** The NWFSC maintains the infrastructure for many critical data management functions, laboratory facilities, field sampling and administrative activities. Building, office, laboratory, library facilities and sea-water systems are required to achieve research goals. Recently, the Center worked collaboratively with NOAA Fisheries Headquarters and MAKERS Consultants to develop a "Northwest Science Facilities Strategic Plan" that identifies facilities needs to support the NWFSC's science priorities now and into the future, and recommends actions to achieve that vision (see below, "Strategies for future needs"). Research activities at the NWFSC are supported by facilities in Washington (Montlake, Mukilteo, Manchester, Pasco) and Oregon (Point Adams, Newport).

   - ***Data management*** at the NWFSC is used to efficiently generate science guidance products such as ESA status reviews, MSFCMA stock assessments and IEAs. The Center must also have the capacity to archive, compile and inter-relate numerous independent data types running into the millions of records. A standardized protocol for data security needs to be developed and supported to protect the Center's large investment in electronic data. The entire Center staff needs to be involved in a discussion of how to identify and support Data Stewards for research and corporate data that are maintained by Center staff; and the Center needs to have a data management strategy that meets the needs of multiple scales of data management.

   - ***Data exchange:*** In addition to internal data management, plans are needed to exchange data with the fishing industry in near-real-time and link our data systems to the larger pool of fishery, environmental (e.g., satellite, buoy, IOOS), and economic data that are becoming increasingly available. Knowledge gained through effective data integration and analysis will allow the Center to better respond to rising research priorities ecosystem-based fishery management and climate change.

   - ***Laboratory facilities*** are important in achieving research goals. Although many facilities are already operational, modernization of these facilities will better allow NWFSC scientists to conduct state-of-the-art science. Some identified needs include specialized laboratories and support personnel (e.g., molecular biology, environmental chemistry), fish culture facilities and wet labs, and computational resources.

   - ***Vessels and aircraft for research:*** Large-scale, interdisciplinary ocean research requires the use of large, sophisticated research vessels capable of extended cruises in rough sea conditions. The broad nature of oceanographic sampling requires many sensors of atmospheric and ocean conditions and the ability to deploy and retrieve many gear types. Estuarine and riverine sampling do not pose the logistic limitations in ship size as does ocean sampling. The NWFSC owns and operates a fleet of small boats necessary for nearshore and estuarine research activities. The NWFSC also relies on both NOAA and chartered commercial vessels and, to a lesser degree, relies on aircraft to complete mission critical field work. The NWFSC is committed to maintaining and expanding the functionality of available operational days of NOAA ships and aircraft by continuing to work closely with NOAA's Office of Marine and Aviation Operations and by working with the commercial community to retain access to and use of chartered ships and aircraft. Furthermore, Puget Sound is an estuary of regional significance. The NWR and NWFSC support the cross agency Puget Sound Habitat Initiative. To maintain needed survey capability the NWFSC is seeking partnership in acquiring a research vessel with the capability to sample in the key sub basins of Puget Sound.

   - ***Gear storage:*** Gear storage needs for sampling gear including ATVs, equipment, boats, nets, trawls and other field and laboratory gear have become acute in recent years. Dedicated and accessible storage for this gear is critical.

   - ***Observer office and training facility:*** Additional space for the Observer Program is needed to house observer staff and provide for meeting and training activities, as well as storage of equipment, samples and supplies. This consolidation will greatly improve cost effectiveness and efficiency of the program.
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4. **Science Communications:** Targeted communication advances NOAA's goal of science, service, and stewardship. The Center provides graphic design, web design, writing, media, social media, internal communications, and strategic outreach support to Center scientists and managers and works in close collaboration with NOAA Fisheries Communications Team, West Coast Regional Office Communications Team, and other partners in and outside of the agency. High quality outreach and education efforts enable the NWFSC to (1) better fulfill its responsibilities to provide the scientific basis to meet NOAA's stewardship role by a) ensuring resource managers and others have the scientific information they need to conserve and manage marine and anadromous species and their habitat and b) by creating a well-informed public that understands earth systems and acts as a steward of coastal and marine ecosystems (Communications, Media, and Strategic Outreach), (2) ensure a dynamic, diverse, and interdisciplinary future workforce with competencies critical to advancing earth system research, both now and in the future (Education) and (3) facilitate flow of information necessary for staff to do their jobs well (Internal Communications).

5. **Strategies to meet future facilities needs:** Although the NWFSC has made and continues to make substantial investments into the tools needed further our research objectives, modifications to facilities have typically been in response to changing demands rather than planned changes for future facility needs. This reactive approach is inefficient, and does not prepare NWFSC to accommodate new technologies or respond timely to emerging research needs (i.e., aquaculture, climate change, ecosystems, habitat restoration, marine planning, and socioeconomics). To sustain state-of-the-art science for emerging research efforts, Center leadership worked collaboratively with NOAA Fisheries HQ and MAKERS Consultants to develop a "Northwest Science Facilities Strategic Plan'. This facilities strategic plan provides a comprehensive outline of the facilities needed to support the NWFSC's mission, today and tomorrow. It identifies areas of current and future research focus, presents a vision for facilities needed to support the science priorities, and recommends actions to achieve that vision.

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The six recommendations actions include:
- Modernize the Fisheries Science Headquarters at either the University of Washington campus west of 15th Avenue NE or the existing Montlake site.
- Update Manchester to support Aquaculture Research and species recovery.
- Construct a Center for Puget Sound Science at Mukilteo.
- Invest in continuing collaborative research at Newport.
- Continue to support Fish Ecology research at Pasco. Evaluate the operational and financial ramifications of potential future divestment.
- Consolidate coast and estuary research in Astoria.

The current focus is exploring the strategic alignment with the University of Washington on benefits of co-location, furthering our relationship with Oregon State University on the ecology of the northern California Current by means of joint research at OSU's Hatfield Marine Science Center, Newport Oregon, and pursuing the final clearance of the transfer of the Mukilteo field station site from the Department of Defense to NOAA. Further progress on these program plans is contingent on funding.

An important regional transportation project will have direct impacts on the NWFSC research headquarters in Seattle, WA. The Seattle headquarters facility is located adjacent to the 520 transportation corridor that connects Seattle to the east side of Lake Washington. The 520 Bridge Replacement and High Occupancy Vehicle Program seeks to "enhance safety by replacing the aging floating bridge and keep the region moving with vital transit and roadway improvements throughout the corridor (http://www.wsdot.wa.gov/Projects/SR520Bridge/)." The NWFSC goal is to help this important regional priority move forward while maintaining our ability to do cutting-edge science.

Support staff

The NWFSC research activities require dedicated and knowledgeable technical and support staff to design, prepare, stage, and maintain critical equipment and instruments and facilities. The Center's research brings together many disciplines, including fisheries science, marine biology and ecology, genetics, biochemistry, molecular biology, oceanography, and physiology. In addition, many of the Center's research projects are conducted in cooperation with other organizations, including federal, state, local, tribal, and academic entities throughout the region, nation, and world. The NWFSC must continue to dedicate staff and budgetary resources for operations and administrative functions. Continued information technology support is critical to ensure computer systems are secure and functional and to develop and maintain necessary databases and applications for research and administrative functions. Laboratory, field, and office safety is a priority and an essential part of successful performance of NWFSC research. Staff with the expertise and resources to maintain our facilities, and to ensure workplace safety and environmental compliance are critical support functions that must be supported.

Partnerships

Partnerships with other international, federal, state, academic, tribal and private organizations maximize the utility of scientific information and provide an excellent means for collaborations that enhance the NWFSC's ability to achieve its goals and objectives. Successful partnerships leverage talent, funding, and capacity that usually result in greater outcomes than any individual entity could do on its own. Examples of partnerships with international science organizations include the North Pacific Marine Science Organization, International Council for the Exploration of the Sea, North Pacific Anadromous Fish Commission, Pacific Salmon Commission, and the Department of Fisheries and Oceans Canada. The NWFSC has partnered with state agencies such as Washington State Departments of Fish and Wildlife, Natural Resources, Ecology, and Health, as well as academic institutions – University of Washington, Washington State University, and Oregon State University. The NWFSC also partners with the Northwest Indian College to familiarize indigenous students to NOAA science used to address important regional issues. Several NWFSC Strategic Science Plan themes and foci (e.g., seafood safety, aquaculture, habitats, ecosystem-based management, species sustainability) align closely with issues of importance to our tribal constituents.

Implementation strategy

Accompanying the Strategic Science Plan will be an Implementation Process, outlining the processes for resource allocation, decision-making and communication to accomplish core activities and high priority research. While this is envisioned as a separate document, the Implementation Process and Strategic Science Plan will work together as guiding documents for the NWFSC.

Each year, NWFSC leadership develops a regional Annual Guidance Memo, closely aligned with priorities of NOAA, which are outlined in NOAA's Annual Guidance Memorandum (AGM), NOAA's Next Generation Strategic Plan (NGSP), and NOAA Fisheries priorities. The NWFSC has developed a comprehensive Project Database that is a compilation of all projects being conducted at the Center, including information on area of research, staff involvement, budgets, and other metadata components. The database organizes research activities in a concise manner, together with resources dedicated to each activity. Each activity is aligned to a particular theme or foci and then prioritized. The assessment conducted through the use of the database will then be used, along with the NOAA AGM priorities and regional priorities, to guide development of electronic Annual Operating Plan milestones. Specific progress toward meeting the goals outlined in this research plan is articulated in the electronic Annual Operating Plan and tracked by completion of the identified milestones. In addition, data produced by the projects will be readily available to end-users, complete with associated metadata.

NOAA FISHERIES

U.S. Secretary of Commerce
Penny Pritzker

Acting Administrator of National Oceanic and Atmospheric Administration and Undersecretary of Commerce
Dr. Kathryn D. Sullivan

Acting Assistant Administrator for NOAA Fisheries
Samuel D. Rauch III

Science and Research Director for Northwest Fisheries Science Center
Dr. John E. Stein

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www.nmfs.noaa.gov

OFFICIAL BUSINESS

Northwest Fisheries Science Center
2725 Montlake Blvd. E
Seattle, WA 98112